Towards Track vs Shower Hit-Based Classification Using Deep Learning in LArTPC Experiments

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1. LArTPC Detectors

- **Liquid argon time projection chamber (LArTPC) detectors measure ionization tracks produced by charged particles inside a cryostat filled with liquid argon.**
- **The ionisation electrons drift in an electric field towards wire planes, where their charge is collected and measured.**

Figure 1: On the left, sketch of a LArTPC taken from [1]. On the right, ionisation electrons collected in one wire plane, from ProtoDUNE-SP simulated event.

2. DUNE & ProtoDUNE-SP

The Deep Underground Neutrino Experiment (DUNE) is a next generation long-baseline neutrino experiment. It will consist of three components: Long-Baseline Neutrino Facilities, the near detector complex, and the far detector (DUNE-FD) which will be four 10 kilo tons LArTPC modules [2]. Goals [3]:

- **studying neutrino oscillations**
- **proton decay events**
- **neutrinos from core-collapsed supernovae.**

ProtoDUNE-Single Phase (SP) is a prototype for DUNE-FD and it is installed and commissioned at CERN [4].

3. Pandora Framework

Pandora is a multi-algorithm pattern recognition software used in LArTPC experiments [5].

- **Pandora combines the 2D information/2D images from the wire planes to create reconstructed 3D particles.**
- **Particles are placed in a hierarchy, which identifies parent-daughter relationships, and identified as track or shower-like.**

It has a multi-algorithm approach and this brings several advantages, since each algorithm performs simple tasks and they can be applied in sequence to build up the reconstruction.

Figure 2: Reconstructed hierarchy of a simulated event in ProtoDUNE-SP. The red cluster at the bottom is the parent reconstructed particle for the event whilst the others are daughters of that particle. The line is the detector gap between the two drift volumes of ProtoDUNE-SP.

5. From Local to Global

The approach is to study small patches of the whole event to find useful variables which can be used to characterise every single hit.

- **Around each hit a grid of size 5.25x5.28 cm^2 is built, the chosen hit lies in the central bin in such a way that its relative position in the grid is (0,0) and the coordinates of the other hits are shifted accordingly**
- **The integrated charged is smeared over multiple bins across 1 σ using a Gaussian distribution**

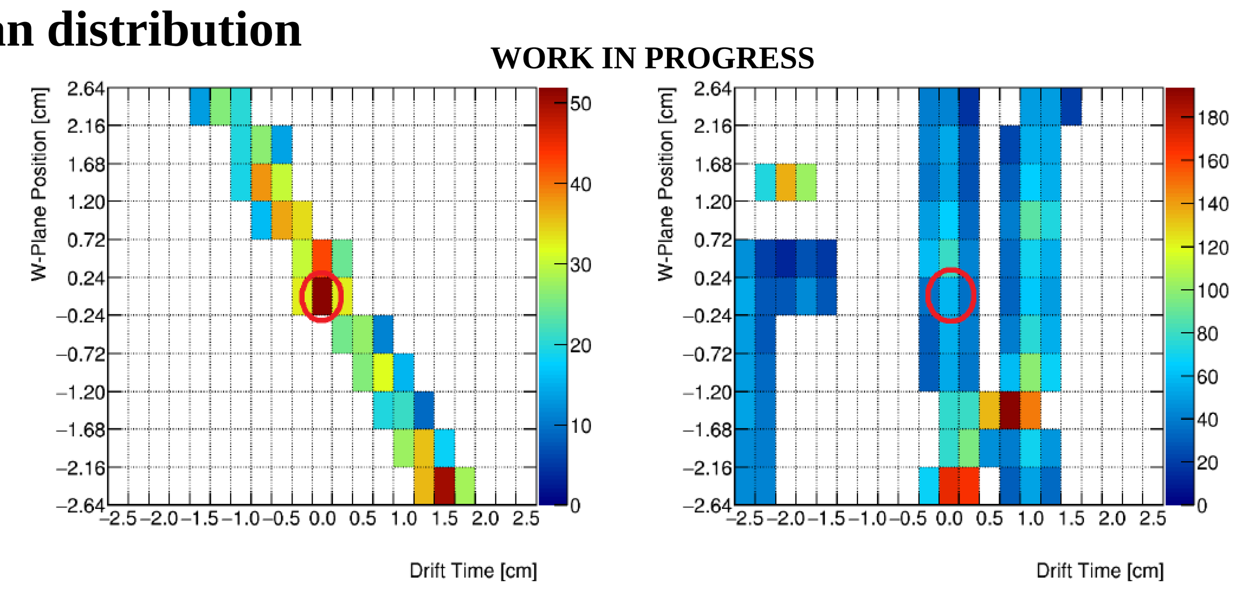

Figure 4: Two examples of grid are shown. The bin the middle inside the red circle is the one where the chosen hit lies, different colours represent different intensities of the integrated deposited charge. Figure 4 left shows a clear track, whilst right is an example of grid in which the topology is not so obvious.

4. Track vs Shower Topologies

Aim: to identify and to separate ionisation tracks passing into electromagnetic shower-like topological regions.

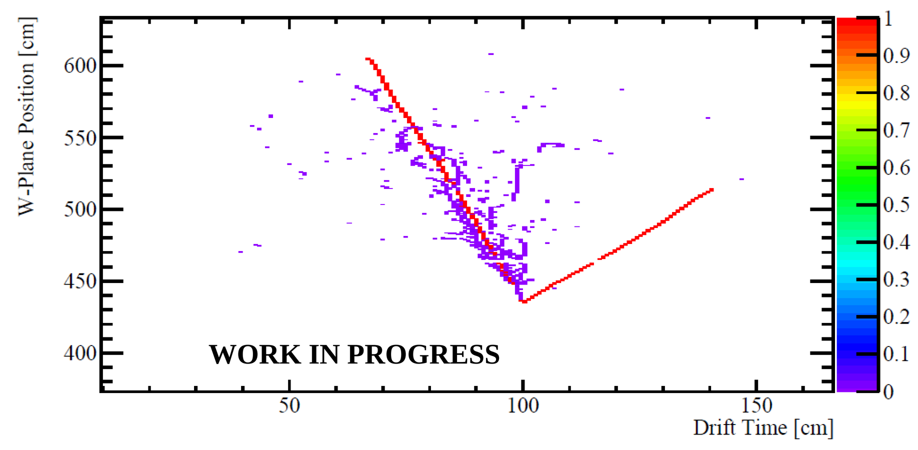

Figure 3: Event characterisation made using Monte Carlo (MC) information from a DUNE-FD simulated event. Track-like particles are coloured in red and shower-like in blue.

6. Finding Variables

- **Various variables have been calculated which could help distinguish between track and shower-like topologies.**
- **As an example, the variable shown is the average distance of the centre of the bins from PCA major axis. For tracks, this value is expected to be small.**

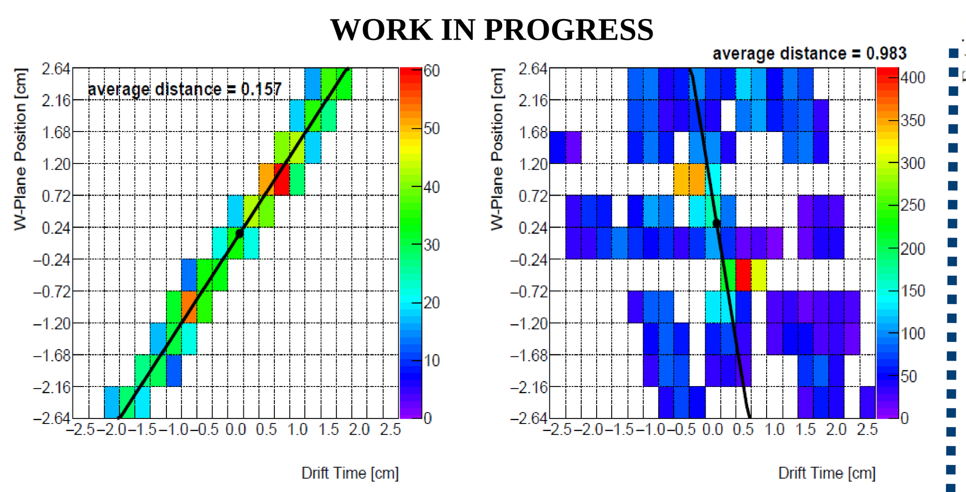

Figure 5: Examples of two different topologies with calculated average distance from PCA major axis (drawn in black).

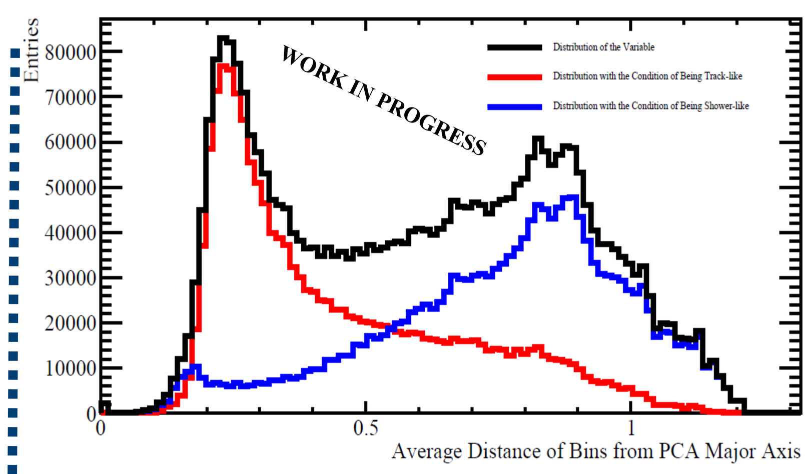

Figure 6: Total distribution (black), and separation obtained with MC values for tracks (red) and showers (blue). Calculated from 3k DUNE-FD simulated events (mix of ν_e and ν_μ interactions).

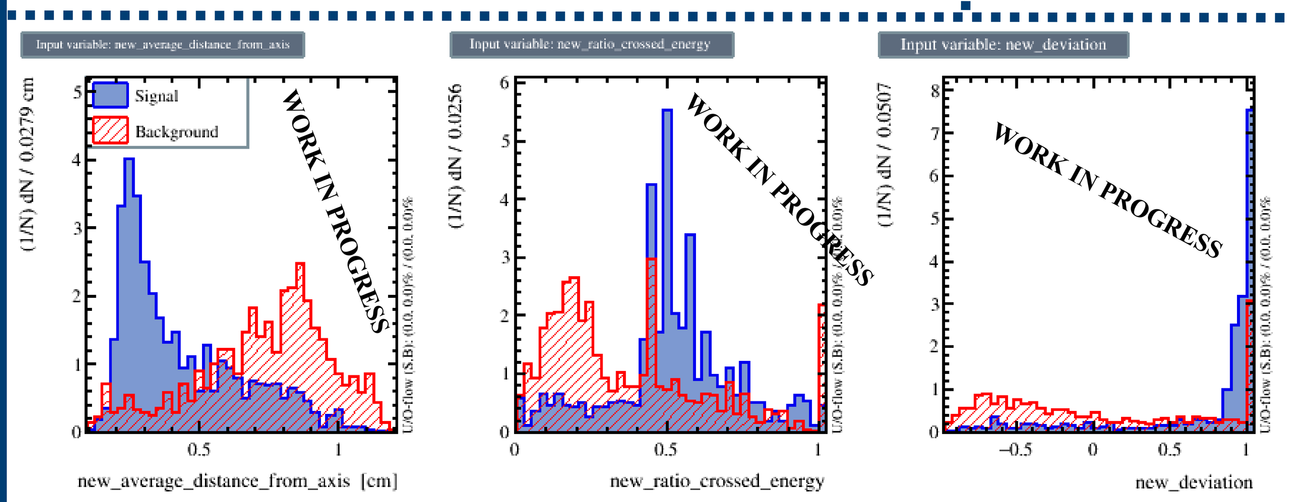

Figure 7: Separation obtained with three variables, calculated from 3k DUNE-FD simulated events (mix of ν_e and ν_μ interactions). Made with TMVA.

7. Results and Future Work

- **Calculated variables from ~ 3k DUNE-FD simulated events have been used for training TMVA and then applied on further ~ 3k DUNE-FD events to avoid overtraining (mix of ν_e and ν_μ interactions).**
- **Results showed that separation between tracks and showers in complicated topological regions is possible.**
- **Future plans include a machine learning/deep learning approach to distinguish also between multiple scenarios (single track, multiple tracks, multiple showers from multiple particles).**
- **This code will be used for Physics analysis on ProtoDUNE-SP such as a cross section measurement.**

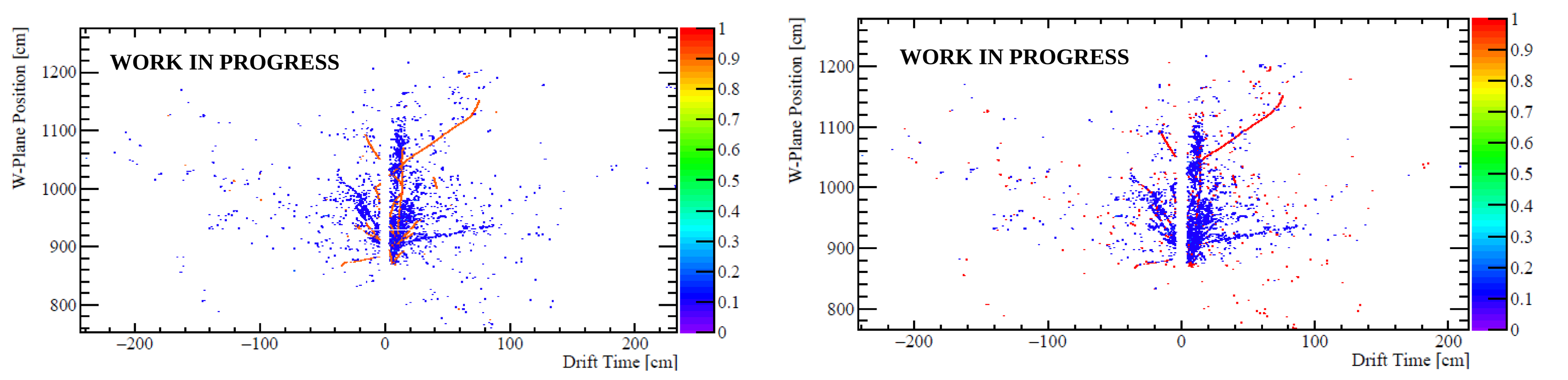

Figure 8: Left shows event from DUNE-FD characterised in blue for shower-like particles and in red for track-like particles with MC true values. Right shows the same event characterised using the algorithm. The gap is a physical gap in the detector.

References:

- [1] MicroBooNE Collaboration, JINST 12, P02017 (2017), arXiv: 1612.05824v2
- [2] Dune Collaboration," Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report, Volume 1: The LBNF and DUNE Projects", FERMILAB-DESIGN-2016-01, arXiv:1601.05471
- [3] Dune Collaboration, "Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report", Volume 2: The Physics Program for DUNE at LBNF", FERMILAB-DESIGN-2016-02, arXiv:1512.06148
- [4] DUNE Collaboration, "The Single-Phase ProtoDUNE Technical Design Report", FERMILAB-DESIGN-2017-02, arXiv:1706.07081
- [5] MicroBooNE Collaboration, Eur. Phys. J. C78, 1, 82 (2018), arXiv: 1708.03135